

L 13128-66 EWT(1) IJP(c) GG

ACC NR: AF6000222

SOURCE CODE: UR/0056/65/049/005/1611/1623

AUTHOR: Kallos, R. E.; Faynberg, V. Ya.

ORG: Physics Institute im. P. N. Lebedev, Academy of Sciences SSSR (Fizicheskii institut Akademii nauk SSSR) 28 B

TITLE: Quantum field theory equations in the axiomatic approach

SOURCE: Zhurnal eksperimental'noy i teoreticheskoy fiziki, v. 49, no. 5, 1965, 1611-1623

TOPIC TAGS: quantum field theory, S matrix, matrix function, difference equation

ABSTRACT: The purpose of the investigation was to determine the invariant properties of the S-matrix elements previously derived by one of the authors (Faynberg, ZhETF v. 47, 2285, 1965 and earlier) for an axiomatic formulation of quantum field theory, and to obtain in explicit form equations for n-point diagrams in difference or integral form, with the quasilocal term eliminated. It is shown within the framework of this formulation that the undetermined quasilocal terms can be expressed in terms of R-functions when the values of some of the invariants are fixed. An analysis is made of the invariants on which the v-functions on the mass shell depend, the range of variation of these invariants in the equation, and

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L 13128-66

ACC NR: AF6000222

the best choice of independent variants in the case of an arbitrary n-point diagram. The invariant properties of the retarded matrix elements of v-functions are used. It is shown that on the mass shell the v-functions depend in the physical region only on invariant scalar products of 4-vectors. Equations in difference form are derived first for 3-, 4-, and 5-point diagrams, and the special nature of the boundary conditions at the threshold and at infinity is explained. The method is then generalized to a 6-point diagram. The equations derived and the prospects for solving them beyond the scope of perturbation theory are briefly discussed. Orig. art. has: 25 formulas.

SUB CODE: 12/ SUBM DATE: 12Jun65/ ORIG REF: 006/ OTH REF: 005

Card 2/2

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OZERSKIY, Z.I., dotsent; FAYNEBERG, Ya.A., kand.ekonomicheskikh nauk

A long-range balance of labor resources of the Sverdlovsk Economic
Administrative Region. Trudy Ural. politekh. inst. no.120:5-14
'61. (MIRA 16:6)

(Sverdlovsk Province--Labor supply)

377. The interaction of a beam of charged particles with electron plasma.
A. I. Akhiezer and Ya. B. Pribludnyy. Dokl. Akad. Nauk, SSSR, 69 (No. 4)
555-6 (1949).

FAYNBERG Ya. B.

6629

On the Cherenkov Effect and the Complex Doppler Effect, A. I. Akhiezer,
G. L. Lyubarskii and Ya. B. Fainberg, Doklady Akad. Nauk S.S.S.R. 73, 55-8
(1950) July 1. (In Russian)

Wave guides with specially devised metal partitions can be constructed in which, even in the absence of dielectrics, the wave phase velocity is smaller than c . A charged particle, moving along such a system with a constant velocity that exceeds the above phase velocity, generates electromagnetic waves, similar to those produced by a Cherenkov electron in a dielectric. The simple case is examined of linear periodic structures forming a succession of cells traversed by a particle through holes in the partitions. A general formula for the intensity of the radiation is first derived, then a special one for the case of a cylindrical wave guide, by using equations of the complex Doppler effect (Frank, Izvest. Akad. Nauk S.S.S.R. 6, 2(1942) obtained from the radiation (resonance) condition.

APPROVED V. B.

Forberg, V. B. On the interaction of a charged particle with a plasma
 1262 1266 1981

On the interaction of an anisotropic beam of charged particles with a plasma. It is shown that the beam of particles is unstable in a plasma with anisotropic pressure. Small fluctuations in the density and velocity of the beam grow in time. This growth is analogous to the growth of waves of increasing amplitude in the same phenomenon as occurs in the passage of a beam of particles through a dielectric, when the velocity of the particles is greater than that of the light in the medium (i.e., when the Cherenkov effect is observed).

G. Taralio di Francia (Firenze)

Mathematical Reviews,

Vol. 13, No. 8

37

0870

8276* *Slow Electromagnetic Waves.* (In Russian.) A. I. Akhiezer and Ya. B. Fainberg. *Uspekhi Fizicheskikh Nauk.* v. 11, July 1951, p. 321-368.
Presents a review of foreign and domestic methods of producing the above, in particular wave conductors (cables), partially filled dielectrics and periodic structures without dielectrics (chain-type endovibrators.) 31 ref.

USSR/Physics - Waveguides

FD-2030

Card 1/1 Pub. 153-21/30

Author : Faynberg, Ya. B and Khizhnyak, N. A.

Title : Artificially Anisotropic Media

Periodical : Zhur. Tekh Fiz, 25, 710-719, 1955

Abstract : Mathematical analysis of propagation of electromagnetic waves in waveguides containing an anisotropic dielectric is presented. Equations expressing E-waves in a cylinder with a periodically varying dielectric are derived and solved. Gratitude for discussions is expressed to A. I. Akhiezer and K. D. Sinelnikov. Seven references, 5 foreign.

Institution :

Submitted : June 15, 1954

FAYNBERG, Ya. B.

✓ 7793

ON THE INTERACTION OF BOUND ELECTROMAGNETIC
RESONATORS WITH A BEAM OF CHARGED PARTICLES.
A. L. Akhiezer and Ya. B. Fainberg. Zhur. Tekh. Fiz. 25,
2516-25 (1955) Dec. (In Russian)

The investigation showed that when a beam of charged
particles, with continuous velocities above a certain critical
term pass through a chain of coupled resonators, the fluctu-
ating charge density and the velocities expand in the beam
in a wave like shape of increasing amplitude. The electrical
field also resembles the expanding waves of increasing am-
plitude. A connection was established between the waves of
increasing amplitude and Cherenkov radiation in dielectric
or periodic structures. (auth-tr)

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FAYNBERG, Ya B.

✓ Alezer, A. I., Lyubarskii, G. Ya. and Faynberg, Ya. I.
On the radiation of charged particles moving in
coupled resonators

Phys. Rev. D
velocity in a periodic structure
used is based on regarding the structure as
producing forced oscillations in the structure
fields then associated with resonant modes

index, 7 H. K.

VERKIN, B.I.; MIL'NER, A.S.; ROZENTSVEYG, L.N.; FAYNBERG, Ya.B.; KHOTKEVICH,
V.I.; SHKLYAREVSKIY, I.N.

Sections of Experimental, Theoretical, and General Physics at the
Department of Physics and Mathematics, 1930-1955. Uch.sap.KHGU
60:63-79 '55. (MIRA 10:1)

(Kharkov University--History)
(Physics)

FAYNBERG, Ya.G.

Charge density waves in non-uniformly moving charged particle
beams. Uch.zap. KHGU 64 no.6:31-34 '55. (MIRA 10:7)
(Particles, Elementary) (Electric charge and distribution)

FAYNBERG, Ya.B.; KHIZHNYAK, N.A.

Artificially anisotropic media. Uch.zap. KHOU 64 no.6:35-36
'55. (MIRA 10:7)

(Anisotropy)

VALENTIN, YA.P., SIMONIKOV, R.D., ZELDIN, P.M. (U.S.S.R.)

Modifications of the Linear and cyclical methods.
of acceleration

CERN-Symposium on High Energy Accelerators and Pion
Physics

Geneva 11-23 June 56
In Branch #5

SAINT-LOUIS, Mo. (U.S.A.)

Alternating phase focusing and use of ^Qplasma waves
for accelerating particles

CERN-Symposium on High Energy Accelerators and Pion
Physics

Geneva 11-23 June 56
In. Branch #5

appeared in Nuclear Instruments, No. 1, pp. 21-30, 1957.

E-BYNERG Y.B.

position of the electrons into enclosed and not a point
in approximation lead to dependence of the position of the
diffraction on frequency and position of the electron

amf

FAYNBERG, Ya. B.

USSR/Electronics - Gas Discharge and Gas-Discharge Apparatus

H-7

Abs Jour : Ref Zhur - Fizika, No 3, 1957, No 7148

Author : Akhiezer, A.I., Lyugarskiy, G.Ye., Feynberg, Ye.B.

Title : Contribution to Nonlinear Theory of Oscillations in Plasma

Orig Pub : Uch. zap. Khar'kovsk. un-ta, 1956, 64, 73-80

Abstract : Owing to the mathematical difficulties, encountered in the solution of the rigorous nonlinear problem of the oscillations in plasma, the authors restricted themselves to the consideration of three particular cases. They studied oscillations occurring upon interaction of an electron beam with the plasma at absolute zero. They considered the excitation of plasma by an infinite charged plane. A considerable portion of the work is devoted to the consideration of nonlinear oscillations excited in plasma in the cases of temperature other than zero. While in the first two cases the hydrodynamic approximation was used exclusively, in the latter case the plasma is represented by the kinetic equation. The results obtained are compared with the results of the linear theory.

Card : 1/1

FAYNBERG, Ya. B., AKHYEZER, A. I., LYUBARSKIY, G. Ya.

"Cerenkov Radiation and the Stability of Beams in the Wave Guides
of Slow Waves used in Linear Accelerators," paper presented at CERN
Symposium, 1956, appearing in Nuclear Instruments, No. 1, pp. 21-30, 1957

X FAYNBERG, Ya. B.

"The Use of Plasma Waveguides as Acceleration Structures
in Linear Accelerators" paper presented at CERN Symposium, 1956,
appearing in Nuclear Instruments No. 1. pp. 21-30, 1957

AUTHOR
TITLE

FAYNBERG, Ya.B., KHIZHNYAK, N.A.

56-4-31/52

PERIODICAL

The Energy Losses of a Charged Particle at its Transition through a Layer-Shaped Dielectric I.
(Poteri energii zaryazhenney chastitsey pri perekhozhenii cherez sloi-
styy dielektrik, I. Russian)
Zhurnal Eksperim. i Teoret. Fiziki, 1957, Vol 32, Nr 4, pp 883 - 895
(U.S.S.R.)

ABSTRACT

Let the particle be in uniform motion in the layer-shaped dielectric. The paper under review determines a general expression for the losses when the particle is in motion in a layer-shaped medium and in a wave guide (charged with a layer-like dielectric). At the uniform motion of a particle through a layer-shaped (periodic with respect to space) medium it is possible to realize conditions under which a forced parametric resonance takes place. The parametric Cherenkov effect then probably has different characteristic properties. In considering the energy losses of the particle in the layer-shaped medium, the authors of the paper under review start out from a system of Maxwell equations describing the interaction of a charged particle in uniform motion with the electromagnetic waves propagating in this medium. The ansatz for the solution for the components of the electromagnetic field is made in the form of a Fourier's integration, - the course of the computations is discussed step by step and then the parametric Cherenkov radiation is in-

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56.4-31/52

The Energy Losses of a Charged Particle at its Transition through a Layer-shaped Dielectric I.

vestigated. If an isotropical dielectric is decomposed into layers, the frequency widens to a frequency band, and in this band a strong Cherenkov radiation takes place. The energy losses caused by the radiation increase and become comparable to the polarization losses. In the usual dielectrical, the losses caused by polarization decrease only in very thin layers. (No reproduction).

ASSOCIATION

Physical-Technological Institute, Academy of Sciences of the Ukrainian SSR.

PRESENTED BY

SUBMITTED

29 April 1956

AVAILABLE

Library of Congress

Card 2/2

HYPERKIS, YA.B.

TABLE 1 BOOK EXPLANATION

Abstracts from Ukrainian SSR. Otdel'nyye fiziko-khimicheskiye nauki.

Study (Presentations of the Section on Physical Uses of Atomic Energy). Kiev, 1958. 100 p. 2,500 copies printed.

Step, M.I., M.V. Pashchuk, Doctor of Physics and Mathematics) Editorial Board: A. E. Val'ner, Academician, Academy of Sciences Ukrainian SSR, O.F. Smets, Academician of Physics and Mathematics, M.V. Pashchuk, Doctor of Physics and Mathematics, M. of Publishing House: T. E. Pashchuk, Tech. Ed.

FOREWORD: This collection of articles is intended for physicists and scientists personally working in nuclear research.

CONTENTS: The articles in this collection discuss linear proton accelerators, electron accelerators, electrostatic accelerators, magnetic lenses, the interaction of charged particles with matter, the application of the application of charged particles in physics research and technology. Some of the articles are descriptions of already existing installations and some are descriptions of new installations. No personal data are mentioned. There is a bibliography of books and non-book sources at the end of most of the articles.

Abstracts, E.D., P.M. Zoritsa, I.A. Gritsenko, L. D. El'yashenko, V.I. Ablyayev, Ya. B. Pashchuk, A.E. Val'ner, and S. A. Dzhuravskiy, Electron Accelerator with an Output Energy of 3.5 MeV.

Val'ner, A.E., and A.A. Dykalo. A Low-Energy Electrostatic Accelerator for Precision Particle Measurements.

Abstracts, E.D., and P.I. Gritsenko. A 2-MeV Horizontal-Type Electrostatic Accelerator.

Ablyayev, A.E., and A.D. El'yashenko. Interaction of Fast Deuterons with Protons.

Ablyayev, A.E., A.E. Val'ner, and S. E. Izraelson. Reaction of $D_2^{16}O$ with Deuterons.

Abstracts, E.D., and M. P. Anisimov. Cross-Sections in Reactions of Proton Capture by Helium Isotopes and Energy Levels of the Helium Nucleus.

Abstracts, E.D., and V. D. Pashchuk. Investigation of Elastic Scattering of Deuteron Energy Protons on Nickel and Copper Nuclei.

Val'ner, A.E., and S. A. Dzhuravskiy. Elastic Scattering of Deuterons by Nickel, Copper, Lead, Manganese and Uranium Nuclei.

Abstracts, E.D., and M.V. Pashchuk. Proton Spectrometer in the $D_2^{16}O$ System.

Abstracts, E.D., V.D. Pashchuk, B.D. Kostomarov, O.F. Smets, and M.V. Pashchuk. Spectra of Fast Neutrons Scattered by Atomic Nuclei.

Abstracts, E.D., V.D. Pashchuk, G.S. Kopylov, M.V. Pashchuk, and V. I. Shchegolev. Scattering Cross Sections of Fast Neutrons.

Abstracts, E.D., V.D. Pashchuk, and G. Ya. Lushchik. Effective Boundary Conditions for Multiple-Scattering Media Interference by Resonant Zonal Neutron Scattering and the Use of Radioactive Isotopes.

Abstracts, E.D., V.D. Pashchuk, and G. Ya. Lushchik. The Method of Representing the Mechanism of Reflected Neutron Spectra by This Method.

Abstracts, E.D., V.D. Pashchuk, and G. Ya. Lushchik. The Method of Representing the Mechanism of Reflected Neutron Spectra by This Method.

Abstracts, E.D., V.D. Pashchuk, and G. Ya. Lushchik. The Method of Representing the Mechanism of Reflected Neutron Spectra by This Method.

Frage: Was die Todesurabstimmung im Parlament

Die Herstellung der Plasmazum elektromagnetischer Wellen aus einem Plasma, das sich in einem Hochstromkanal bewegt, welches sich an einer Stelle in einem Magnetfeld befindet, haben wir in den folgenden Figurellaren [21] im Programm der elektronischen Wille bestrahlt.

$\frac{1}{2} \left(\frac{1}{2} + \frac{1}{2} \right) = \frac{1}{2}$

The Virasoro algebra is also formulated in the following form (9.1)

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WALSH & THE PERRY FAMILY. BOSTONIAN IN THE

$$m = 1, 2, \dots, n$$

100

[illegible]

4. Anwendung: Die Frage der Debatte der „Kontinuität“ ist in der Tat ein zentraler Punkt der Debatte der „Kontinuität“ und ist ein zentraler Punkt der Debatte der „Kontinuität“.

[illegible]

Literature

- [illegible]

21

Topic/Issue

QUESTIONS

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International Conference on the Neosporal Mass of Atomic Energy, St. Gerners, 1958
Library available university reference plain (Reports of Soviet Scientists
Soviet Physics) Moscow, Atomizdat, 1959. 528 p. (Series: The Study, Vol. 2)
8,000 copies printed.

[illegible]

NOTE: This collection of articles is intended for scientific research workers and other persons interested in nuclear physics. The volume contains 4 papers presented by Soviet scientists at the Second Conference on Peaceful Uses of Atomic Energy, held in Geneva in September 1959.

contents: It is divided into two parts. Part I contains 17 papers dealing with plasma physics and controlled thermonuclear reactions, and Part II contains 16 papers on nuclear physics, including problems of particle acceleration and of nuclear energy. The first paper by L.A. Arvidson presents a survey of controlled nuclear reactions. The remaining papers in Part II work on controlled thermonuclear reactions. The remaining papers in Part I deal with controlled nuclear reactions in this field.

There is much work to be done in solving the various problems in nuclear physics reported in Part II, both in the field of elementary particles and in the study of such as the dynamics of heavy atoms and their isotopes, and with the study of the interaction of particles with matter, and the study of the properties of the nucleus and the nucleus as a whole. The Russian-language edition of the proceedings of the 1964 International Conference on Nuclear Physics, held in Moscow, contains all the information on the results of the conference. The Russian-language edition of the proceedings of the 1964 International Conference on Nuclear Physics, held in Moscow, contains all the information on the results of the conference. The Russian-language edition of the proceedings of the 1964 International Conference on Nuclear Physics, held in Moscow, contains all the information on the results of the conference.

[illegible][illegible]

The Great American Novel, by Richard B. Sewall, pp. 280, \$6.95; *The Great American Novel*, by Richard B. Sewall, pp. 280, \$6.95; *The Great American Novel*, by Richard B. Sewall, pp. 280, \$6.95.

1992-1993 / 2000

Source of Sample Submitted: Dealer (Cont.)

Secretary, R.A. and V.S. Industries.
1074 (Barnet St.)

Stability of Phase by Ins-
ulation, E. B., and S. I. Braginsky.
Soviet Atomic Energy (Engng. Ed.)

Address: A. I., D. B. Ryndorf, A. G. Skelton, L. B. Starnes, V. L. Harrison,
The L. F. Gordon Co., 1000 Broadway, New York, N. Y.

(Subject - You)

Subject, B. B., and V. B. Shumway,
Floodways, Inc., 10000 1st Avenue, S.W.,
Seattle, Wash. 98148 (Subject - B.B.)

Adoption of High Frequency

Address, A.L. G. B. Lybrandt, and E.V. Solovik-
Bank Three in Washington, D.C. (1937)

Respectably, S. L. and V. B. MacCreary.
Readers (before 1900)

33

FAYNBERG, Ya.B.; KHIZHNYAK, N.A. [Khyzhniak, M.A.]; Silenok, G.A.
[Silenok, Ho.O.]; BEREZIN, A.K.; NEKRASHEVICH, A.M.
[Nekrashevych, O.M.]

Spiral wave guide with an artificially anisotropic dielectric.
Part 1. Ukr.fiz.zhur. 4 no.4:451 J1-Ag '59. (MIRA 13:4)

1. Khar'kovsk'y gosudarstvennyy universitet im.Gor'kogo.
(Wave guides) (Dielectrics)

BEREZIN, A.K.; NEKRASHEVICH, A.M. [Nekrashevych, O.M.]; SILENOK, G.A.
[Sylenok, H.O.]; FAYNBERG, Ya.B.; KHIZHNYAK, N.A. [Khyzhniak, M.A.]

Spiral wave guide with an artificially anisotropic dielectric.
Part 2. Ukr.fiz.shur. 4 no.4:460-464 J1-Ag '59. (MIRA 13:4)

1. Khar'kovskiy gosudarstvennyy universitet im. Gor'kogo.
(Wave guides) (Dielectrics)

FAYNBERG, Ya.B.; NEKRASHEVICH, A.M. [Nekrashevyoh, O.M.]

Modulation of linear accelerators of heavy particles by means
of slow electrons. Ukr.fiz.zhur. 4 no.6:803-804 N-D '59.
(MIRA 14:10)

1. Fiziko-tekhnicheskii institut AN, USSR.
(Particle accelerators)

SOV/89-6-4-6/27

21(9)

AUTHOR:

Faynberg, Ya. B.

TITLE:

The Acceleration of Particles in a Plasma (Uskoreniye chastits v plazme)

PERIODICAL:

Atomnaya energiya, 1959, Vol 6, Nr 4, pp 431-446 (USSR)

ABSTRACT:

The physical reasons are explained upon which the new method of linear particle acceleration is based. The novelty of this acceleration is the fact that plasma-wave guides or not compensated electron- or ion beams are used as accelerator systems. For such systems the dynamic behavior of the particles to be accelerated is theoretically investigated and the results are given. In nonlinear approximations the propagation of electromagnetic waves for a narrow plasma wave guide is investigated. Acceleration of particles by means of nonlinear longitudinal waves in the plasma and the excitation of such waves are studied. The question as to the adiabatic invariants for wave motions in a plasma which are connected with particle acceleration are discussed. The method of amplifying high-frequency electromagnetic fields is described, and the results to be obtained in this way are given. The method is based upon the fact that the electromagnetic waves are reflected on

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The Acceleration of Particles in a Plasma

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a moving plasma. A number of results obtained by this paper was discussed with A. I. Akhiezer, V. I. Veksler and G. I. Budker. There are 23 references, 10 of which are Soviet.

SUBMITTED: September 3, 1958

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SOV/89-6-4-7/27

21(9)

AUTHOR:

Faynberg, Ya. B.

TITLE:

The Nonlinear Theory of Slow Waves in the Plasma
(K nelineynoy teorii medlennykh voln v plazme)

PERIODICAL: Atomnaya energiya, 1959, Vol 6, Nr 4, pp 447 - 452 (USSR)

ABSTRACT:

By means of nonlinear methods of approximation the propagation of electromagnetic waves in a narrow plasma wave guide is dealt with theoretically. The dependence of phase velocity on amplitudes is derived and determined. The problem concerning frequency multiplication is investigated and an expression is found for the amplitude of the second harmonic. The nonlinear effects offer a new possibility of influencing the phase velocity of waves by amplitude variation. In this way it is possible to attain both radial and phase-stability in the accelerator. This influence makes it possible also to modify microwave amplification and -production. The results obtained were discussed with K. D. Sinel'nikov and A. I. Akhiezer. The paper was submitted to the scientific council of the FTI AN USSR (FTI, AS UkrSSR) in 1956. There are 6 references, 3 of which are Soviet.

~~Classified~~

FAYNBERG, Ya.B.; KURILKO, V.I.

[Adiabatic invariants for a plasma in a magnetic field]
Ob adiabaticheskikh variantakh dlia plazmy v magnitnom
pole. Khar'kov, Fiziko-tekhn. in-t AN USSR, 1960. 297-
303 p. (MIRA 17:2)

FAYNBERG, Ya.B.

[Some aspects of particle acceleration in a magnetic field]
Nekotorye voprosy uskoreniia chastits v plazme. Khar'kov,
Fiziko-tekhn. in-t AN USSR, 1960. 393-413 p. (MIRA 17:2)

FAYNBERG, Ya.B.; KHIZHNYAK, N.A.

[Discharge density waves in modulated electron beams]
Volny plotnosti zariada v modulirovannykh puchkakh.
Khar'kov, Fiziko-tekhn. in-t AN USSR, 1960. 425-448 p.
(MIRA 17:1)
(Electromagnetic waves) (Electron beams)

ZAGORODNOV, O.G.; FAYNBERG, Ya.B.; YEGOROV, A.M.

Reflection of electromagnetic waves from a plasma moving in slow-wave guides. Zhur. eksp. i teor. fiz. 38 no.1:7-9 Jan '60.
(MIRA 14:9)

(Electromagnetic waves) (Plasma (Ionized gases)) (Wave guides)

KHARCHENKO, I.P.; FAYNBERG, Ya.B.; NIKOLAYEV, R.M.; KORNILOV, Ye.A.;
LUTSENKO, Ye.A.; PRUDENKO, N.S.

Investigating the interaction between an electron beam and
plasma. Zhur.eksp.i teor.fiz. 38 no.3:685-692 Mr '60.
(MIRA 13:7)

1. Fiziko-tekhnicheskii institut Akademii nauk Ukrainakoy
SSR.
(Electron beams) (Plasma (Ionized gases))

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S/089/61/011/004/001/008
B102/B138

24.6714
AUTHOR:

Faynberg, Ya. B.

TITLE:

Interaction between charged-particle beams and plasma

PERIODICAL:

Atomnaya energiya, v. 11, no. 4, 1961, 313 - 335

TEXT: The article reviews material published on the problems of controlled thermonuclear reactions. Besides the author, V. I. Kurilko, I. F. Karchenko, and V. D. Shapiro contributed material. First, excitation of plasma oscillations by a charged-particle beam and instability problems are discussed (instabilities due to a Cherenkov effect when electron or ion beams are interacting with a plasma in a magnetic field; instabilities due to anomalous Doppler effect; instabilities due to normal Doppler effect). Conditions are given for the occurrence of instabilities, and some special cases, e. g., the stellarator, are discussed. Also considered are boundary effects, nonlinear effects, and questions concerning high-amplitude longitudinal waves propagating in a plasma. A short analysis of experimental results is given and, finally, theoretical and experimental results are compared. This comparison shows that (1) most of

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Interaction between...

the plasma instabilities under review have been detected experimentally; (2) their experimentally and theoretically determined fundamental characteristics are in good agreement; (3) the development of instabilities is always accompanied by oscillations and considerable loss in the energy of oriented motion of the beam (~ 100 ev/cm per particle for a plasma with $n_0 \approx 10^{11}$); (4) development of instabilities also causes a considerable increase in the energy of the plasma electrons (10 - 20 kev); (5) the development of instabilities is accompanied by considerable growth in the ion and electron currents transverse to the magnetic field. The following Soviet scientists are mentioned in the article: A. I. Akhiezer, Ya. B. Faynberg (Dokl. AN SSSR, 64, 555 (1949); Zh. eksperim. i teor. fiz. 21, 1262 (1951); V. I. Veksler (Proceedings Symposium CERN, 1, 80 (1956)); V. L. Ginzburg, I. M. Frank (Dokl. AN SSSR, 54, 699 (1947)). I. A. Cherenkov (Dokl. AN SSSR, 2, 451 (1934)); S. I. Vavilov (Dokl. AN SSSR, 2, 457 (1934)); I. Ye. Tamm, I. M. Frank (Dokl. AN SSSR, 14, 107 (1937)); G. V. Gordeyev (Zh. eksperim. i teor. fiz. 23, 660 (1952); 27, 19, 24 (1954)); A. A. Vedenov, Ye. P. Velikhov, R. Z. Sagdeyev (Usp. fiz. nauk, 73, 701 (1961)); A. V. Gaponov, Zh. eksperim. i teor. fiz. 39, 326 (1960); M. F. Gorbatenko (Sb. Fizika plazmy, t. 1, Kiyev, Izd-vo AN USSR, 1961);

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S/089/61/011/004/001/008
B102/B138

Interaction between...

A. V. Gurevich (Zh. eksperim. i teor. fiz. 39, 1297 (1960));
A. I. Akhiezer, G. Ya. Lyubarskiy, R. V. Polovin (Zh. eksperim. i teor. fiz. 40, 963 (1961)); L. D. Landau, Ye. M. Lifshits (Mekhanika sploshnykh sred - Mechanics of continuous media, M. Gostekhizdat, 1955);
Ya. B. Faynberg, V. I. Kurilko, V. D. Shapiro (Zh. tekhn. fiz., 31, 632 (1961)); G. I. Budker (Atomnaya energiya, no. 1, 5 (1956)); O. G. Zagorodnov, Ya. B. Faynberg, B. I. Ivanov, L. I. Bolotin (Zh. tekhn. fiz., 31, 574 (1961)); I. F. Kharchenko, Ya. B. Faynberg, R. M. Nikolayev, Ye. A. Kornilov, Ye. I. Lutsenko, N. S. Pedenko (Zh. eksperim. i teor. fiz. 38, 685 (1960)); A. A. Zaytsev, G. S. Leonov, I. A. Savchenko (Zh. eksperim. i teor. fiz., 36, 1332 (1959)); M. D. Gabovich, L. L. Pasechnik (Zh. eksperim. i teor. fiz., 36, 1024 (1959)); Ye. V. Bogdanov, V. Ya. Kislov, Z. S. Chernov (Radiotekhnika i elektronika, 5, 229 (1960)); I. F. Kharchenko, Ya. B. Faynberg, R. M. Nikolayev, Ye. A. Kornilov, Ye. I. Lutsenko, N. S. Pedenko (Zh. tekhn. fiz., 31, 761 (1961)). There are 6 tables and 79 references: 52 Soviet and 27 non-Soviet. The four most recent references to English-language publications read as follows: L. Spitzer. Phys. Fluids. 3, 659 (1960); P. Sturrock. Phys. Rev., 117, 1246 (1960); M. Allen, G. Kino. Phys. Rev. Letters, 6, 163, (1961);

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27520
S/089/61/011/004/001/008
B102/B138

Interaction between...

R. Post, W. Perkins, Phys. Rev. Lett. 6, 85 (1961).

SUBMITTED: July 28, 1961

Card 4/4

211.01
S/089/61/011/006/001/014
B102/B138

24.6716
AUTHORS:

Berezin, A. K., Faynberg, Ya. B., Berezina, G. P.,
Bolotin, L. I., Stupak, V. G.

TITLE: Interaction of strong electron beams with plasma

PERIODICAL: Atomnaya energiya, v. 11, no. 6, 1961, 493 - 497

TEXT: The energy losses of a nonmodulated electron beam passing through an air plasma were determined. Beam voltage was 26 kev, amperage 8 a, electron density $(7-9) \cdot 10^{10} \text{ cm}^{-3}$, and pressure in the discharge tube $3 \cdot 10^{-4} - 4 \cdot 10^{-3} \text{ mm Hg}$. The quartz plasma tube, 64 cm in length, was arranged so that the greater part of the plasma was outside the focusing magnetic field (2000 oe). The electron gun, a LaB₆ disk 10 mm in diameter, was perpendicular to the magnetic field and was with voltage pulses of up to 30 kev, a width of 3.5 μsec , and repetition frequency of 50 cycles. This gun was able to produce current pulses of 9 a at the plasma chamber input, where the focusing field was 1200 oe. In the field-free region amperage decreased with increasing flight path down to 2 - 3 a due to Coulomb

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Interaction of strong...

interaction. The plasma density was measured by a cylindrical cavity excited with a TM_{030} wave from a klystron. The upper limit of measurement was $4 \cdot 10^{10} \text{ cm}^{-3}$. Its value during the passage of current was determined from the plasma decay law: $n = n_0 \exp(-t/\tau)$, where τ is the mean time for plasma decay and n_0 the density at $t=0$. The straight line $n(t)$ was drawn from three measurements and extrapolated toward $t=0$. Maximum electron density was $7 \cdot 10^{10} \text{ cm}^{-3}$, while the value $9 \cdot 10^{10} \text{ cm}^{-3}$ resulted from shf-interferometric measurements. The electron energy spectrum was recorded by means of a beam catcher connected to an oscillograph. These spectra were investigated at the input and output of the plasma tube, and for pressures of $4 \cdot 10^{-3}$ and $3 \cdot 10^{-4}$ mm Hg, for which losses reached 11% and 1% of the initial energy, respectively. Conclusions: Energy losses increase with plasma density and with current, and are proportional to the electron mean free path in the plasma. Calculation of losses due to elastic collisions between electrons and gas molecules yields ≈ 0.04 ev, and ≈ 3 ev for those due to inelastic collisions. Coherent interaction, however, causes losses of 3.2 kev if self-modulation of the beam is assumed to reach X

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Interaction of strong...

40%. This is in good agreement with experiments. There are 6 figures and 13 references: 10 Soviet and 3 non-Soviet. The four references to English-language publications read as follows: D. Bohm, E. Gross, Phys. Rev., 75, 1851, 1864 (1949); D. Bohm, E. Gross, Phys. Rev., 79, 992 (1950); V. I. Veksler, Proc. Symp. CERN, 1, 80 (1956); M. Biondi, S. Brown, Phys. Rev., 75, 1700 (1949).

SUBMITTED: June 17, 1961

Care 3/3

X

ZAGORODNOV, O.G.; FAYNBERG, Ya.B.; YEGOROV, A.M.; BOLOTIN, L.I.

Frequency multiplication with the aid of plasma collapse.
Zhur. tekhn. fiz. 31 no.3:297-300 Mr '61. (MIRA 14:3)
(Plasma (Ionized gases))(Frequency multipliers)

22778

S/057/61/031/005/009/020
B104/B205

24.2/20 (1049, 1163, 1532)

AUTHORS: Zagorodnov, O. G., Faynberg, Ya. B., Ivanov, B. I., Us, V. S.,
and Bolotin, L. I.

TITLE: Non-linear effects in the propagation of electromagnetic
waves in a plasma waveguide

PERIODICAL: Zhurnal tekhnicheskoy fiziki, v. 31, no. 5, 1961, 574-576

TEXT: An experimental study has been made of non-linear distortions of sinusoidal electromagnetic waves in a plasma. Non-linearities of this kind occur when the velocity of the plasma electrons interacting with the wave becomes comparable to the phase velocity of the waves. The experiments were conducted with a cylindrical plasma column of 1 cm diameter and 160 cm length, produced by a d-c discharge in mercury vapor within a longitudinal magnetic field. The signals at the input and the output of the discharge tube were conveyed to a double-beam oscilloscope. The dependence of the ratio a_n/a_1 (a_1 - amplitude of the i-th harmonic) on the spacing of the two spirals exciting and receiving the electromagnetic

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Non-linear effects...

waves (see Fig. 1) shows that a sinusoidal signal undergoes distortion at a distance of 10 cm and acquires a sawtooth shape. Fig. 2 shows a_2/a_1 as a function of a_1 for different amplitudes of the input signal and different densities of the plasma. It was found further that non-linearities are also produced by a decrease in plasma density, due to the decreasing phase velocity of the waves and the growing amplitude of the signal in the plasma. It is concluded that a sinusoidal signal is distorted by a non-linear plasma. The sawtooth signal observed at the output undergoes further distortion with increasing non-linearity. There are 4 figures and 4 references: 2 Soviet-bloc and 2 non-Soviet-bloc.

ASSOCIATION: Fiziko-tekhniicheskiy institut AN USSR Khar'kov (Institute of Physics and Technology, AS UkrSSR, Khar'kov)

SUBMITTED: July 30, 1960

Card 2/A2

23717

S/057/61/031/006/001/019
B109/B207

24.2120 (3717, 3817, 153P)

AUTHORS:

Faynberg, Ya. B., Kurilko, V. I., Shapiro, V. D.

TITLE:

The character of instabilities in the interaction between charged particle beams and plasma

PERIODICAL:

Zhurnal tekhnicheskoy fiziki, v. 31, no. 6, 1961, 633-639

TEXT: The problem of convective and absolute instabilities is treated by the method of L. D. Landau and Ye. M. Lifshits (Mekhanika sploshnykh sred. GIITL, 1954). In papers by A. I. Akhiezer, Ya. B. Faynberg (DAN SSSR, 64, 555, 1949; ZhETF, 21, 1262, 1951), D. Bohn, E. Gross (Phys. Rev., 75, 1851, 1949), and G. I. Budker (Atomnaya energiya, I, 5, 1956), the solution of equations for small vibrations was formulated in the form

$$\varphi(\vec{r}, t) = \varphi(y, z)e^{i(kx - \omega t)} \quad (1)$$

with the criterion of instability for the existence of complex roots of the dispersion relation $\phi(k, \omega) = 0$. The question as to the character of the occurring instabilities remains, however, unsolved. According to Landau and Lifshits, a distinction should be made between convective and

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The character of instabilities in the...

absolute instabilities; in this connection, the behavior of the integral

$$\int_{-\infty}^{+\infty} \exp\{-i\omega(k)t\} dk \quad (4)$$

plays the decisive role. The study of this integral by the method of Landau and Lifshits, which, for several reasons, is better than that of P. A. Sturrock (Phys. Rev., 112, 1488, 1958), must be carried out for all parts $\omega_\alpha(k)$ of the dispersion relation; for this purpose, the path of integration of (4) is changed according to Fig. 1. The curve C in the ω -plane (Fig. 2) with the integral

$$\int_C e^{-i\omega t} \frac{d\omega}{dk} \quad (5)$$

corresponds to this path of integration. Points of type ω_1^* do not lie on the examined sheet of the $\omega(k)$ plane; points of type ω_2^* make no contribution; consequently, (5) takes the form $\int_{-\infty}^{\infty} e^{-i\omega t} \frac{d\omega}{dk}, (I)$. If $t \rightarrow \infty$, only

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the range $\omega \sim \omega_j^*$ remains; hence,

$$\frac{d\omega}{dk} \approx \left[2 \frac{d^2\omega}{dk^2} \Big|_{\omega_j} (\omega - \omega_j) \right]^{1/2},$$

$$\int_{\omega_j}^{\omega} e^{-i\omega t} \frac{d\omega}{dk} = \frac{2e^{-i\omega_j t}}{\left[2i - \frac{d^2\omega}{dk^2} \Big|_{\omega_j} \right]^{1/2}} \int_0^{\omega} e^{-i\omega t} \frac{d\omega}{\sqrt{\omega - \omega_j}} = \frac{e^{-i\omega_j t}}{\left[\frac{i}{2\pi} \frac{d^2\omega}{dk^2} \Big|_{\omega_j} \right]^{1/2}}. \quad (6)$$

All other $\omega(k)$ are treated in the same way. Then, a cold plasma (density n_0) interacting with a monoenergetic electron beam of density n_1 and velocity V_1 is considered. After introduction of the usual frictional force $m\nu_{\text{eff}}\vec{v}$ ($\nu > 0$), the dispersion relation acquires the form

$$\frac{1}{X(X+i\nu)} + \frac{\alpha}{(X-Y)(X-Y+i\nu)} = 1, \quad (I)$$

$$X = \frac{\omega}{\omega_0}; \quad Y = \frac{kV_1}{\omega_0}; \quad \nu = \frac{\nu_{\text{eff}}}{\omega_0}; \quad \alpha = \frac{n_1}{n_0}; \quad \omega_{0,1}^2 = \frac{4\pi e^2}{m} n_{0,1}.$$

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The character of instabilities in the...

The points to be surrounded are determined by

$$\begin{aligned} Y_{\text{per}}^{\pm} &= \pm \frac{iv}{2} \left[\frac{1 + \alpha - \frac{v^2}{4}}{\alpha - \frac{v^2}{4}} \right]^{1/2} \\ X_{\text{per}}^{\pm} &= -iv \pm \left[\frac{1 + \alpha - \frac{v^2}{4}}{\alpha - \frac{v^2}{4}} \right]^{1/2} \end{aligned} \quad (\text{III})$$

(Fig. 3). The points X_{per}^{\pm} , which, together with (6), might lead to an exponential increase of perturbation with time, are meaningless (type ω_2^*); here and also in the case $v < 0$ the instability is convective (Tak mechanism). At plasma temperatures other than zero, the dispersion relation with the usual notation and simplifying assumptions reads

$$\frac{1}{X^2 - \beta^2 Y^2} + \frac{a}{(X - Y)^2} = 1, \quad (7);$$

$$\beta V_1 = V_{\infty}; \quad a n_0 = n_1; \quad \omega_0 X = \omega; \quad \omega_0 Y = k V_1.$$

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The character of instabilities in the...

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if $\beta^2 \ll \alpha \ll 1$, one has

$$\begin{aligned} X_{\text{per}} &= \pm \left\{ 1 + 2\beta\alpha^{1/2} e^{i\pi m} + 2\beta^{3/2} \alpha^{1/4} e^{\frac{i\pi}{2}m} \right\} \quad m = 0, 1, 2, 3. \\ Y_{\text{per}} &= \pm \left\{ \alpha^{1/4} e^{\frac{i\pi}{2}m} + \frac{3}{4}\beta^{1/2} + \frac{3}{32} \frac{\beta}{\alpha^{1/4}} e^{-\frac{i\pi}{2}m} \right\} \quad (\text{IV}), \end{aligned}$$

which again results in a convective instability. Small vibrations in a system consisting of two oppositely directed beams of charged particles, are described by the following dispersion relation:

$$\frac{\omega_1^2}{(\omega - kV_1)^2} + \frac{\omega_2^2}{(\omega + kV_2)^2} = 1, \quad \omega_{1,2}^2 = \frac{4\pi^2}{m} n_{1,2}, \quad (\text{VII}),$$

where $n_{1,2}$ and $V_{1,2}$ denote the density and velocity of the beams. On the assumption that $V_1 = V_2$ and $n_1 = n_2$, it can be seen that if $t \rightarrow \infty$, (4) increases as $\frac{\exp(\omega_0 t/2)}{\sqrt{t}}$ (non-convective case). The instability is also

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9,3130 (1163,1538,1141)
24.6716

25021
S/057/61/031/007/001/021
B108/B209

AUTHORS:

Kharchenko, I. F., Faynberg, Ya. B., Nikolayev, R. M.,
Kornilov, Ye. A., Lutsenko, Ye. I., and Pedenko, N. S.

TITLE:

Interaction of an electron beam with a plasma in a magnetic
field

PERIODICAL: Zhurnal tekhnicheskoy fiziki, v. 31, no. 7, 1961, 761-765

TEXT: The interaction between a beam of charged particles and a plasma has great physical and technical significance and is therefore subject to the present study. In a plasma in a magnetic field, an electron beam may interact with both E and H waves. Moreover, parameter resonance may occur since the arising waves lead to a change of the parameters which is periodical in space and time. When the frequency of the plasma particles stands in a certain ratio to the frequency of the electromagnetic field forming by self-modulation of the electron beam when moving through a plasma, parameter resonance is possible. This ratio between the frequency of the longitudinal waves, due to the interaction between beam and

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Interaction of an electron beam ...

plasma, and the cyclotron frequency ω_H is given by $\omega = \frac{2\omega_H}{p}$ or by

$\frac{2\pi v}{L} = \frac{2\omega_H}{p}$ where L is the periodicity of the wave in the beam, v_0 the velocity of the beam ($p=1,2,\dots$). However, also other instabilities may arise when an electron beam interacts with a plasma. The experimental arrangement for the present studies provided a 50-ma electron beam (5 kev)

to interact with a plasma in a vacuum of $10^{-2} - 10^{-3}$ mm Hg. The magnetic field strength during the experiment was 2000 gauss. The results showed that at certain magnetic field strengths the electron beam becomes unstable, which leads to a widening of the glowing plasma (from 3 to 30 mm) and a decrease in the beam energy. When the electron beam was pre-modulated on a frequency f_m , instability occurred at four magnetic field strengths corresponding to the electron-cyclotron frequencies of $\frac{1}{2}f_m$, f_m , $\frac{3}{2}f_m$, and $2f_m$. The width of these unstable ranges was only a few per cent of the cyclotron frequency. The h. f. oscillations generated in the unstable zone

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Interaction of an electron beam ...

in the beam (1800 to 3000 Mc/sec, half-width 30 - 50 Mc/sec) offer the possibility of obtaining millimeter waves by further increasing the magnetic field strength. Further results are announced to be given in a following paper. This paper was read at the Second Conference on Magnetohydrodynamics, Riga, July 1960. There are 3 figures, and 8 references: 6 Soviet-bloc and 2 non-Soviet-bloc.

ASSOCIATION: Fiziko-tekhnicheskiy institut AN USSR Khar'kov (Institute of Physics and Technology AS UkrSSR Khar'kov)

SUBMITTED: October 3, 1960

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S/861/62/000/000/001/022
B125/B102

AUTHORS: Akhiezer, A. I., Feynberg, Ya. B.
TITLE: Linear acceleration of charged particles (introductory article)
SOURCE: Teoriya i raschet lineynykh uskoriteley; sbornik statey. Fiz.-
tekhn. inst. AN USSR. Ed. by T. V. Kukoleva. Moscow,
Gosatomizdat, 1962, 5 - 18

TEXT: The development of linear accelerators since 1946 has been promoted by the disadvantages of cyclic accelerators, viz., large magnets, large radiative losses in high-energy electron acceleration, low amperage of the particle beam. The magnetic systems of linear accelerators need not be large. Such accelerators ensure continuous operation and high phase stability; also they furnish much heavier currents than cyclic accelerators. They produce almost no radiation, and can be extended by adding on sections. Hitherto it has not been possible to combine radial stability with phase stability, but even without special focusing this will be rendered possible in plasma wave guides. The highest electron energies achieved using linear accelerators are ~660 Mev. Linear proton accelerators of ~50 to ~100 Mev

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Linear acceleration of...

and linear ion accelerators serve as injectors for cyclic accelerators. Linear acceleration up to several BeV is thought possible. Self-stabilization of phase allows of accelerating many injected particles. The following types of linear accelerators now exist: (1) Periodic structures of waveguide accelerators with perforated metal discs are at present the most effective accelerators where phase velocities are extremely high ($v_{ph} \rightarrow c$). These are ineffective for low phase velocities ($v_{ph}/c \sim 0.3$ to 0.5). (2) When filled with anisotropic dielectrics, waveguides can also be used for low phase velocities. (3) Periodic structures with drive tubes spaced along the axis are very efficient for $v_{ph} \sim 0.3$ to 0.4 . Disadvantages become manifest if the length of these accelerators or the phase velocity is increased. Small local changes in the parameters of an individual element affect the field strength considerably, because of the strong coupling between the individual elements. (4) Slow waves can be produced using helical waveguides.

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44872

S/861/62/000/000/002/022
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24.6730

AUTHOR: Faynberg, Ya. B.

TITLE: The dynamics of charged particles in a linear traveling-wave accelerator

SOURCE: Teoriya i raschet lineynykh uskoriteley, sbornik statey. Fiz.-tekhn. inst. AN USSR. Ed. by T. V. Kukoleva. Moscow, Gosatomizdat, 1962, 19 - 37

TEXT: The radial and phase stability in the acceleration of particles (especially protons) by the field of a slow ($v_\phi < c$) traveling wave (superposition of E waves and H waves) in linear accelerators is investigated by integrating the equation of motion for the particles. The present results are valid also for the acceleration of electrons to low energies or in weak fields. The Lagrangian $L = -mc^2\sqrt{1-\beta^2} + (e/c)\vec{A}\vec{v} - e\varphi$ yields the equations of longitudinal and radial motions

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The dynamics of charged...

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$$\frac{d}{dt} \frac{mr}{\sqrt{1-\beta_z^2}} = \frac{1}{2} eE_0 k_z \cos \psi_s (1-\beta_z^2) r_s - \quad (10)$$

$$- \frac{mr\omega_H^2 \sqrt{1-\beta_z^2}}{4} \left[1 - \left(\frac{r_s}{r} \right)^2 \right]; \quad (11)$$

$$\frac{d}{dt} \frac{mz}{\sqrt{1-\beta_z^2}} = eE_0 \sin \left[\omega t - \omega \int \frac{dz}{v_\phi(z)} + \psi_s \right].$$

where the Bessel functions are replaced by their limits for $k_1 r \rightarrow 0$:
 $I_0(k_1 r) \rightarrow 1$, $I_1(k_1 r) = k_1 r/2$. v_ϕ is the phase velocity of the wave, ω its frequency, $k_z = \omega/v_\phi$, $k_1^2 = (\omega^2/v_\phi^2) - (\omega^2/c^2)$, ψ_s is the synchronous phase and E_0 is the accelerating field strength. For an moving particle, the wave field has the phase $\psi(t, z) = \omega t - \omega \int dz/v_\phi(z)$. $E_z \sim I_0(k_1 r) \exp[\omega t - \omega \int dz/v_\phi(z)]$ holds when the criterion $dv_\phi/dz \ll \omega I_0(k_1 r)/k_1 r I_1(k_1 r)$ for the adiabatic
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The dynamics of charged...

(slow) variation of the phase velocity is fulfilled. According to (10) and (11), the radial defocusing forces can be diminished by the longitudinal magnetic field of the wave. In the nonrelativistic case,

$$v_{\phi}(z) = v_s(z_s); \quad \frac{dv_{\phi}}{dz} v_{\phi} = \frac{dv_s}{dz}. \quad (16a)$$

holds for the phase motion when the adiabaticity condition is fulfilled. The condition of phase stability is $0 \leq \psi_s \leq \pi/2$. The phase oscillations are given by

$$\psi \sim \left(\frac{v_{\phi}}{v_s(t)} \right)^{1/2} \cos \left[\gamma \left(\frac{v_s(t)}{v_s} \right)^{1/2} - \psi_0 \right].$$

when the WKB method can be applied. In the relativistic case

$$\left[\sqrt{\frac{v_0^2}{\Omega^2(0)} + \frac{v_0^2}{\Omega^2(0)}} \left[\frac{v(0)}{v_s(t)} \right]^{1/2} \cdot \left[\frac{\cos \psi_{s0}}{\cos \psi_s} \right]^{1/2} \cos \left[\int \Omega dt + \alpha \right].$$

holds for small phase deviations. The velocity spread is $\sim (1-\beta_s^2)^{3/4}$ if the WKB method can be applied. In the extremely relativistic case, linear

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The dynamics of charged...

accelerators can operate without phase stability. The radial motion in linear accelerators is given by

$$r = \frac{1}{2} \left[\frac{\Omega(0)}{\Omega(t)} \right]^{1/2} \left[\left(r_0 + \frac{\dot{r}_0}{\Omega(0)} \right) \exp \int_0^t \Omega(t) dt + \left(r_0 - \frac{\dot{r}_0}{\Omega(0)} \right) \exp - \int_0^t \Omega(t) dt \right]$$

The electric field has an accelerating component E_z and a radial component E_r . Even synchronous particles can be defocused in linear accelerators. The condition for radial focusing is $(\pi e E_0 / m \beta_s \lambda) \cos \psi_s < 0$. Phase stability cannot be attained simultaneously with radial stability without special focusing. The present paper was written in 1947.

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44875

S/861/62/000/000/006/022
B125/B102

24 6730

AUTHORS: Sinel'nikov, K. D., Faynberg, Ya. B., Zeydlits, P. M.
TITLE: A possible modification of the linear and cyclic methods of acceleration
SOURCE: Teoriya i raschet lineynykh uskoriteley, sbornik statey. Fiz.-tekhn. inst. AN USSR. Ed. by T. V. Kukoleva. Moscow, Gosatomizdat, 1962, 109 - 113

TEXT: A type of accelerator combining the advantages of cyclic and linear accelerators is discussed. It is a linear accelerator bent to a nonclosed ring or another non-closed curve. The accelerated particles are kept in their trajectories of constant or variable radius by a magnetic field. Radial and axial stability is attained in the way customary for cyclic accelerators. Phase stability can be achieved using the dependence of the revolution period of the accelerated particles on their frequency. High energies can be attained in systems of large radius and comparatively moderate field strength (~ 1 kgauss for 1 Bev). The condition of phase stability is $\Omega_{\varphi}^2 = eV_H^2 N^2 k / \epsilon$, where Ω_{φ} is the frequency of the phase

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A possible modification of the...

oscillations and N is the number of the periods of the linear accelerator. The frequency of the generator can be kept constant by varying the structural period of the linear accelerator. The advantages of such accelerators are simplicity of injecting and extracting particles, considerable increase of the beam current, constancy of the generator frequency and of the magnetic field strength. The energy gained per revolution is of the same order of magnitude as the total energy. The magnetic field is a function of radius and angle. When the quasistationarity condition

$\Omega_{\varphi}^2/\omega_H^2 \ll 1$ is fulfilled and when the magnetic field strength and the number N of the periods of the accelerating system vary slowly, $\omega_r = N\omega_H$ is the condition of synchronism between particle and wave. The generator frequency, therefore, is significantly higher than the revolution frequency of the particle. The radial deviations Δr_1 for radial-phase oscillations and Δr_2 for free radial oscillations can be diminished significantly to $\Delta r_1 = 1-6$ cm and $\Delta r_2 = 1-5$ cm. Rather large variations in momentum and in amplitude of the phase oscillations then correspond to small radial variations. Near the end of acceleration, the amplitude of the radial oscillations decreases by

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A possible modification of the...

several times because of the considerable increase in magnetic field strength after one revolution. This paper was written in 1955.

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44876

S/861/62/000/000/007/022
B125/B102

246730

AUTHORS: Akhryezher, A. I., Lyubarskiy, G. Ya., Pargamanik, L. E.,
Paynberg, Ya. B.

TITLE: Prebunching and dynamics of a proton bunch in a linear
accelerator

SOURCE: Teoriya i raschet lineynykh uskoriteley; sbornik statey. Fiz.-
tekhn. inst. AN USSR. Ed. by T. V. Kukoleva. Moscow,
Gosatomizdat, 1962, 114 - 130

TEXT: It is shown that a linear accelerator can have a low injection energy
of ~ 0.5 Mev whilst furnishing large currents of ~ 10 to 50 mA. When the
mean accelerating field strength is 20 kv/cm a focusing magnetic field of
15,000 oe is needed in the initial part of the accelerator. This focusing
field becomes rapidly weaker with increasing particle energy. The efficien-
cy of ion capture is increased by π -lystron bunching. When particles in a
bunch that was originally homogeneous in velocity and density pass along a
segment under an rf field, and immediately afterwards through a field-free
drive segment, they are accelerated at different rates and form bunches of
charge density. The preaccelerated particles must enter the accelerator at
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Prebunching and dynamics of...

the focus $X_1 = v_0/\omega$. $\alpha = eU/mv_0^2$. $U \sin \omega \tau$ is the modulated voltage applied to the acceleration segment, τ the instant when the particle enters the segment, and v_0 the initial velocity of the particle in the bunch. The greater the angular width of the group of particles, the tighter the bunch is pinched on klystron bunching. If Δv_0 is the initial velocity spread, then the phase range covered after bunching by particles entering the buncher with a velocity of $v_0 + \Delta v_0$ in the phase range $2\psi_0$ is $\phi = 2\psi_0(1 - (\sin \psi_0/\psi_0)(1 - 3\Delta v/v_0))$. The effective accelerating field on the accelerator axis can be undesirably attenuated by unequal attenuations of the fields on the axis and on the periphery of the gaps and also by a shift of the field into the drive tube. Long narrow tubes screen considerably better than short wide tubes. According to experimental studies in the Institut khimicheskoy fiziki AN SSSR (Institute of Chemical Physics AS USSR), the mean value of the electric field strength on the axis remains constant when the gap between the drive tubes is varied, and it increases slightly when the outer diameter of the drive tubes is increased. The problem of multiple gaps cannot be solved from the data available at present. The decreases in the depth of the potential well and in the angle of

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Prebunching and dynamics of...

incidence, induced by space charge, are calculated on the basis of the model of an ellipsoidal bunch with slowly changing dimensions. Stable equilibrium corresponds to the synchronous particle phase $\varphi = \varphi_s$. In that model the focusing magnetic field reads

$$\left(\frac{H}{E}\right)^2 = \frac{mc^2}{eE\lambda} \left\{ \frac{mc^2}{eE\lambda} \left(4\pi \frac{\Omega}{\omega}\right)^2 + 4\pi \frac{\sqrt{1-\beta^2}}{\beta^2} \sin \varphi_s + \right. \\ \left. + \frac{6J}{cEI} \left(\frac{\lambda}{R}\right)^2 (1-k) \right\}. \quad (4.1).$$

$\omega = 2\pi c/\lambda$ is the frequency of the r-f field, $2l$ the length of the bunch and Ω the frequency of the radial oscillations. The magnetic fields needed for injection energies of 0.5, 18.75, 145 and 350 Mev are 14.5, 7.6, 6.2 and 5.9 koe. The values $\Delta\beta/\beta = 2\%$ for the initial relative velocity spread in the bunch, and $\alpha = 2.2 \cdot 10^{-2}$ for the modulation factor of the buncher are obtained. There are 9 figures.

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24.6/30
AUTHORS:

Akhiyev, A. I., Lyubarskiy, G. Ya., Faynberg, Ya. B.

TITLE:

Electron counterflow focusing in a proton accelerator

SOURCE:

Teoriya i raschet lineynykh uskoriteley; sbornik statey. Fiz.-
tekhn. inst. AN USSR. Ed. by T. V. Kukoleva. Moscow,
Gosatomizdat, 1962, 131 - 146

TEXT: A theory is developed on counterflow focusing of a proton bunch (Nature, 168, 782, 1951). Radial focusing is achieved by the electrostatic field of the electron beam, which has to be stronger than the defocusing r-f field. Furthermore, the scattering of the electrons from the background gas is studied, taking space charge into account. The minimum amperage of the bunch is $j_{\min} = (1/2)(vE/\beta\lambda)\sin\varphi_s$. v is the electron velocity averaged over the period of the r-f oscillations, φ_s the synchronous phase, β the proton velocity, and λ the wavelength of the r-f field. The h-f field of the accelerator is taken to be a traveling wave of amplitude E_0 , frequency ω and wave vector $k(z)$. The canonical variables Q and P are introduced:

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Electron counterflow focusing...

$$Q = \frac{\partial f}{\partial P} = \left(\frac{2u}{\alpha v_0} - t \right) \omega, \quad p = \frac{\partial f}{\partial z} = \frac{\omega P}{v_0 u}, \quad \text{where } f = P \omega \left(\frac{2u}{\alpha v_0} - t \right). \quad \text{Then}$$

$$\Delta H_1 = \frac{1}{\omega} \int_0^{2\pi} \frac{dH_1}{dt} \frac{dQ}{\frac{v_{es}}{u v_0} - 1} \quad (1.15),$$

if $H_1 = H + \frac{\partial f}{\partial t}$ and $\frac{dH_1}{dt} = \frac{\partial H_1}{\partial t}$, ΔH_1 is the change of H_1 during a period during which Q changes by 2π . $u = (1 + \alpha z)^{1/2}$, $\alpha = 2eE \cos \varphi_s / M v_0^2 > 0$, and v_0 is the injection velocity of the protons. When $E = 18$ kv/cm, $v_0 = 3.3 \cdot 10^{-2} c$, $\varphi_s = 20^\circ$ and $\lambda = 150$ cm, H_1 increases nearly linearly with H_0 . The larger β , the larger H_1 . $\Delta H_1 / H_1 \approx 10^{-2}$ holds in the initial stage of the motion of the electron. The greater the velocity of the electrons in the bunch, the greater must be the density of the electron bunch needed for focusing. The total amperages under the present conditions at injection energies ($mc^2(\gamma - 1)$) of 1, 10, 50, 70 and 90 kev are 3.5, 1.9, 1.2, 1.06 and 0.7 a. S. Chandrasekhar's methods give

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Electron counterflow focusing...

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$$\overline{\Delta x^2} = \frac{4\pi N Z^2 e^4}{m^2} \int_0^l [\psi_1^2(r-l) + \psi_2^2(r-l)] \frac{1}{v} \ln \frac{u_0 m v^2}{2Z^2 e^4} dr. \quad (3.13)$$

for the mean square deviation of the electrons from the accelerator axis.

N is the number of gas atoms per cm³, Z the nuclear charge and

$a_0 = 0.53 \cdot 10^{-3}$ cm. For $\sqrt{\Delta x^2} < 10^{-2}$ cm, the magnetic field must be greater than 645 gauss. The effect of collisions on bunch broadening is completely compensated by increasing the magnetic field by 10 to 20 gauss. The significant divergence of the bunch as a result of space-charge repulsion is not impeded by this slight increase in field strength. This paper was written in 1953. There are 1 figure and 4 tables.

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44880

S/861/62/000/000/011/022
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24.6730

AUTHOR: Faynberg, Ya. B.

TITLE: The possibility of simultaneous radial and phase stability in a linear accelerator without special focusing devices

SOURCE: Teoriya i raschet lineynykh uskoriteley; sbornik statey. Fiz.-tekh. inst. AN USSR. Ed. by T. V. Kukoleva. Moscow, Gosatomizdat, 1962, 161 - 173

TEXT: The paper deals with achieving simultaneous radial and phase stability by generalizing the method of focusing that employs alternating focusing and defocusing lenses to cover longitudinal and phase focusing. In a linear accelerator, simultaneous radial and phase stability is impossible without additional focusing devices when $|\Omega_q \tau| \ll 1$ and the signs of Ω_q^2 and Ω_r^2 are fixed. Ω_r and Ω_q are the frequencies of the radial and longitudinal r-f oscillations. The radial and longitudinal motions in traveling-wave accelerators are described by $\ddot{q} + f(t) + q = 0$ (14) and $\ddot{r} - f(t)r/2 = 0$ (15), with

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$$f(t) = \Omega_z^2 - \frac{2\pi e E}{m\beta_\phi(z_s)\lambda} \cos \left(\omega \left(t - \int_0^t \frac{ds}{U_\phi(s)} \right) \right); \quad (12)$$

and

$$\Omega_r^2 = -\frac{f(t)}{2} = -\frac{\Omega_z^2}{2}. \quad (13).$$

f.

These two equations can be stable simultaneously. When the synchronous phase oscillates harmonically with a frequency Ω , where Ω is smaller than the frequency of the r-f field, (14) and (15) go over into two Mathieu equations, and thence, with $\Lambda = \Omega_\phi^2 = -2\pi e E_0 / \lambda m \beta_\phi(z_s)$, $\Omega t = 2\tau$ and

$4\Omega_\phi^2 / \Omega^2 = 2P$, into the canonical Mathieu equation $(d^2y/d\tau^2) + 2P \cos 2\tau y = 0$ (24). When P is small, simultaneous stability of the longitudinal and

radial motions is possible. The frequencies $\tilde{\Omega}_\phi \approx \sqrt{2}\Omega_\phi^2 / \Omega$ and $\tilde{\Omega}_r \approx (1/\sqrt{2})\Omega_\phi^2 / \Omega$

increase with the number n of r-f field periods during one oscillation of the secondary phase. They differ but little from the corresponding frequencies on focusing by foils or grids. n can be so chosen that the frequencies of the phase oscillations and the radial oscillations are sufficiently

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large. For accelerators having an axially symmetrical field of any shape, i.e. no space charges, the basic problem once more comes down to ensuring the existence of two stable domains for the solutions of $\ddot{q} + f(t)q = 0$ (28) and $\ddot{r} - (f(t)/2)r = 0$, where $f(t)$ is a periodic function. When $\int_0^\omega P dt = 0$,

where $P(t)$ is periodic (period ω), there are always stable solutions to equations of the type $d^2y/dt^2 = P(t)y$. When the periodicity μ of the solution is small, the period Ω of the stable oscillations is proportional to μ , and the domain of the stable solutions is independent of the sign of μ . This is precisely the reason why the radial motion and the phase motion can be stable simultaneously. The frequency is greatest when $P(t)$ is a sine function. The work discussed here is useful in dealing with accelerators of high field strength, but demands that the parameters be strictly adhered to. The paper was written in 1953. There is 1 figure.

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44881

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24 (730)

AUTHORS: Selivanov, N. P., Faynberg, Ya. B.

TITLE: The possibility of using traveling-wave linear accelerators to accelerate heavy particles

SOURCE: Teoriya i raschet lineynykh uskoriteley; sbornik statey. Fiz.-tekhn. inst. AN USSR. Ed. by T. V. Kukoleva. Moscow, Gosatomizdat, 1962, 174 - 185

TEXT: The efficiencies of standing-wave and traveling-wave linear proton accelerators are estimated by comparing the specific losses in rf power. A comparatively long time $T_0 \sim 60 \mu\text{sec}$ elapses before the stationary state has become established, and this prevents the use of magnetrons or klystrons for supplying traveling-wave accelerators. Break-down phenomena between the drive tubes precludes increasing the mean accelerating field or shortening the accelerator. Traveling-wave waveguides containing metal discs are calculated using the approximation method of V. V. Vladimirov ("Zh. tekhn. fiz.", 17, 1269 (1947)) and W. J. Hansen (Appl. Phys., 20, 280 (1949)). In Hansen's dispersion equation

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$$\frac{1}{k_1 a} \frac{J_1(ka)}{J_0(ka)} = \frac{J_1(ka) N_0(kb) - N_1(ka) J_0(kb)}{ka [J_0(ka) N_0(kb) - N_0(kb) J_0(ka)]} \quad (3),$$

J, I and N are Bessel and Neumann functions, and $kb = 2\pi b/\lambda$ or $ka = 2\pi a/\lambda$ are the relative radii of the waveguide or of the disc aperture. b and a are the corresponding absolute radii. The phase velocity of the wave increases continuously along the accelerator. Even when the most effective focusing methods available are used, the radius of the proton bunch remains smaller than a. For small phase velocities, the increase in efficiency due to the decrease in b is compensated by increased attenuation of the field in the accelerator. For optimum design of the accelerator, all its parameters have to be properly chosen to render the correspondence complete. When weak accelerating fields are used, the losses in the initial part of a traveling-wave linear proton accelerator are advantageously small. At final energies of 1000 Mev, however, they are about 1.5 times as large as those in standing-wave accelerators. New methods of focusing that are more effective will invert this ratio. Since stronger accelerating fields can be used, a smaller value can be chosen for the total length of a traveling wave proton

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accelerator than for that of a standing wave accelerator. This advantage is largely compensated by the absence of a sufficiently effective method for decelerating the traveling wave. More effective focusing methods, employing waveguides of 10 cm wavelength, will furnish proton bunches a few millimeters in radius; this will considerably increase the efficiency of the traveling wave linear proton accelerator. This paper was written in 1949. There are 6 figures.

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44882

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B125/B102

24,6730

AUTHORS: Selivanov, N. P., Faynberg, Ye. B., Stepanov, K. N.,
Khizhnyak, N. A.

TITLE: Choosing the best variant of a linear proton accelerator

SOURCE: Teoriya i raschet lineynykh uskoriteley, sbornik statey. Fiz.-
tekhn. inst. AN USSR. Ed. by. T. V. Kukoleva. Moscow,
Gosatomizdat, 1962, 186 - 202

TEXT: Two theories are studied: that of waveguides with dielectric discs
fitted inside, used to accelerate protons to high energies, and that of
radial focusing using alternate focusing and defocusing lenses. When the
dielectric constant $\epsilon = \epsilon(x, y, z)$ and the conductivity $\sigma = \sigma(x, y, z)$ are time-
independent, $\Delta \vec{A} + k^2 \vec{A} - \text{div} \vec{A} \cdot \text{grad}(\ln k^2) = -(4\pi/c) \vec{j}$ holds, where

$k^2 = i\omega(10\epsilon + 4\pi\sigma/c^2)$, ω denoting the frequency and \vec{j} the current density.
In the case of an axisymmetric field and zero current the product $A(r, z)$
- $R(r)Z(z)$ is formulated so as to obtain the components of electric and
magnetic field strengths:

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$$\left. \begin{aligned} E_z &= E_0 J_0(mr) e^{i(\omega t - k_z z)}; \\ E_r &= \frac{i E_0 k_z}{\frac{a+b}{ae+b} k_z^2 - \left(\frac{\omega}{c}\right)^2} \frac{m(a+b)}{(a+ib)} J_1(mr) e^{i(\omega t - k_z z)}; \\ H_\phi &= \frac{i E \frac{\omega}{c} m}{\frac{a+b}{ae+b} k_z^2 - \left(\frac{\omega}{c}\right)^2} J_1(mr) e^{i(\omega t - k_z z)}, \end{aligned} \right\} \quad (12).$$

The boundary conditions

$$A|_{z=z_0-0} = A|_{z=z_0+0}; \quad \frac{1}{k^2} \frac{\partial A}{\partial z} \Big|_{z=z_0-0} = \frac{1}{k^2} \frac{\partial A}{\partial z} \Big|_{z=z_0+0}. \quad (2)$$

take account of the jump-like change in the properties of the medium at $z = z_0$. The formulas (12) agree with the known expressions for the components of an electromagnetic field in a waveguide containing an anisotropic dielectric, if the following condition is observed: The discs made of a homogeneous isotropic dielectric, that are fitted inside the waveguide, must be equivalent to an anisotropic dielectric having the effective ϵ components

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$\epsilon_r = (a+cb)/(a+b)$, $\epsilon_z = (a+b)\epsilon/(a\epsilon+b)$. The mean phase velocity in a waveguide containing discs is smaller than that in an empty waveguide; it is greater than that in one containing a dielectric. The attenuation of the fields due to the infinite conductivity is proportional to $e^{-\gamma z/2}$, where

$$\gamma = \frac{4\pi}{c^2} \omega^2 \frac{b}{\sqrt{(a\epsilon+b)(a+b\epsilon)}} \frac{1 - \frac{a}{a+b} \frac{m^2 c^2}{\omega^2} \frac{\epsilon^2 - 1}{\epsilon^2}}{\sqrt{\frac{(a+b)\epsilon}{a\epsilon+b} \frac{\omega^2}{c^2} - m^2}} \quad (13)$$

and $m = 2.405/R$. The power losses per unit length from a waveguide containing dielectric discs amount to $D_1 = (1-e^{-\gamma})S \approx \gamma S$. When the structural

period remains constant, the phase velocity of a wave in a waveguide fitted with dielectric discs is varied by changing the relative thickness $\eta = a/b$ of the discs. Linear accelerators with alternately arranged magnetic lenses possess regions of stable motion in the y and z directions corresponding to certain values of magnetic field gradient and lens length. The stability condition of the motion in such traveling-wave accelerators reads

$$H' = \frac{\pi E \cos \varphi_s}{\beta^2 \lambda} \frac{a_1 + a_2}{a_2 - a_1}, \quad l^2 = \frac{2\pi m \beta \lambda \sigma_x^2}{e E \cos \varphi_s} (a_2 - a_1). \quad (25),$$

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where l is the length of the lens. Proceeding from the equation of motion of a standing wave accelerator with drive tubes when there are six magnetic lenses per period, the condition obtained for the region of stable particle motion is given by

$$\begin{aligned} x &= \frac{\beta\lambda}{4} \sqrt{\frac{4\pi eE \cos \varphi_s}{m\beta\lambda v_x^2}}, \\ y &= \frac{3\beta\lambda}{4} \sqrt{\frac{eH}{mc^2\beta}}. \end{aligned} \quad (41).$$

There are 2 figures and 3 tables.

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S/861/62/000/000/015/022
B125/B102

24 (170)

AUTHORS: Faynberg, Ya. B., Selivanov, N. P.

TITLE: Investigating the initial part of a linear electron accelerator

SOURCE: Teoriya i raschet lineynykh uskoriteley, sbornik statey. Fiz.-
tekhn. inst. AN USSR. Ed. by T. V. Kukoleva. Moscow,
Gosatomizdat, 1962, 211 - 230

TEXT: The accelerating system of this linear accelerator consists of a waveguide fitted with metal discs. When the entrance field strengths are not too high, e.g. $eE_0 \lambda = 180$ kev, and $\beta > 0.5$, the phase oscillations calculated by the quasi-classical approximation method are correct. The phase stability deteriorates in an attenuating field, and is improved by an increasing field. The amplitudes and frequencies of the phase oscillations derived by numerical integration of the equation of motion for the particle agree tolerably well with those calculated in quasi-classical approximation. The numerical results imply a constant waveguide radius in the initial part of the accelerator. The effect of the space charge on the phase velocity of the wave is small anyway if the currents are large; it becomes even

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Investigating the initial part...

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smaller when the relativistic correction is taken into account. The r-f energy absorbed in the accelerated bunch can be disregarded in accelerators of low amperage. For accelerators of large amperage, the energy conservation equation $(\partial W / \partial t) + D + D_1 = 0$ is used to determine the change in the accelerating field strength due to absorption of energy in the bunch, and hence the maximum duration of the accelerated particle pulse for which the condition for particle acceleration is fulfilled. W is the power supply of the accelerator, D the losses in the walls, and D_1 the power absorbed by the bunch. The flux of accelerated particles can be very large when the pulses are short. The longitudinal and transverse electric fields set up by ellipsoidal electron bunches of uniform density are considerably weaker than the accelerating r-f field. Nevertheless, the bunches can greatly affect some of the electrodynamical parameters of the system. This paper was written in 1952. There are 9 figures and 8 tables.

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14885
S/861/62/000/000/016/022
B125/B108

24 6730
AUTHORS: Selivanov, N. P., Faynberg, Ya. B., Gil'man, M. Z.
TITLE: Calculation of a linear electron accelerator for 4 Mev
SOURCE: Teoriya i raschet lineynykh uskoriteley, sbornik statey. Fiz.-
tekhn. inst. AN USSR. Ed. by T. V. Kukoleva. Moscow,
Gosatomizdat, 1962, 231 - 242

TEXT: A travelling $\pi/2$ -wave linear accelerator segmented by annular metal discs (as suggested by V. V. Vladimirovskiy) is calculated with the Walkinshaw-Brillouin (J. Appl. Phys., 20, 634 (1949)) method which ensures high accuracy in determining the phase velocity of the wave and the frequency of the system. The dispersion relation, actually a determinant with an infinite number of rows and lines, need not have more than three rows in order to give sufficiently accurate results. It is derived using the continuity of the tangential components of the electric and of the magnetic fields and solved by graphical means. Leaving the ratio of thickness l of the disks to wavelength λ unchanged, the solution also remains unchanged. It can be used then to calculate the inner radii a of the annular disks for any frequency ω . The spacing between the discs is then determined by suc-
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Calculation of a linear electron...

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cessive approximation for a given h-f power flux S_0 at the input of the accelerator, taking the loss in power into account. The initial 0.7-Mev-section of a 4-Mev linear accelerator was calculated, constructed, and tested at the Fiziko-tekhnicheskiy institut AN USSR (Physicotechnical Institute AS UkrSSR). For $\lambda = 10.6493$ cm, the outer radius of the disks (wave guide) $b = 4.491$, and $l = 0.398$ cm, the results were as follows: The distances between the single discs had to increase from 13.62 mm to 23.94 mm between the first and the 44th disc and the inner diameters $2a$ increased from 31.26 mm to 39.36 mm. Experimental and calculated data were in good agreement, so the entire 4-Mev accelerator was completed after calculations with the same method. Results were very good. The present work was composed in 1953. There are 5 figures and 5 tables.

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44886

S/861/62/000/000/017/022
B125/B108

24,6730

AUTHORS: Akhiyezer, A. I., Faynberg, Ya. B., Selivanov, N. P.,
Stepanov, K. N., Pakhomov, V. I., Kovalev, O. V., Khizhnyak,
N. A., Gorbatenko, M. F., Bar'yakhtan, V. G., Shanshanov, A. A.

TITLE: Linear electron accelerators for high energies

SOURCE: Teoriya i raschet lineynykh uskoriteley, sbornik statey. Fiz,-
tekh. inst. AN USSR. Ed. by T. V. Kukoleva. Moscow,
Gosatomizdat, 1962, 243 - 309

TEXT: This paper, finished in 1955, is a voluminous report on the most important results obtained at the Fiziko-tekhicheskiy institut AN USSR (Physicotechnical Institute AS UkrSSR) between 1948 and 1955 as to the proper choice of an accelerating system and its optimum parameters as well as on the dynamics of the electrons inside the accelerator. One of the most efficient systems is the $\pi/2$ traveling wave type accelerator segmented by annular metal disks (designed by V. V. Vladimirskiy). The calculation of such a waveguide with the Walkinshaw-Brillouin method (J. Appl. Phys., 20, 634 (1949)) is demonstrated. The radial motion of the electrons in a Bevatron accelerator under the action of terrestrial magnetism and gravity should be
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Linear electron accelerator...

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compensated by the combined magnetic fields of rectilinear currents and a small number of electromagnets. In such a case, detectors are necessary indicating the displacement of the beam by the fields of the correcting magnets. Owing to the great length of linear accelerators, an additional radial focusing on the principal section is necessary. In the first section and in the injector this will be achieved by strong longitudinal magnetic fields. In the principal section radial focusing can be achieved by short magnetic lenses (diameter 50 cm) producing a longitudinal magnetic field of ~ 1000 oe/cm, or by a system of four-pole lenses. Both systems can reduce the beam radius at the output of the accelerator to 0.5 cm. There are 1 figure and 18 tables. ✓

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44889

S/861/62/000/000/020/022
B125/B108

24.6730

AUTHORS: Akhiezer, A. I., Faynberg, Ya. B.

TITLE: Theory of the interaction of charged particles with an electron beam in a magnetic field

SOURCE: Teoriya i raschet lineynykh uskoriteley, sbornik statey. Fiz.-tekhn. inst. AN USSR. Ed. by T. V. Kukoleva. Moscow, Gosatomizdat, 1962, 320 - 325 .

TEXT: This paper presents an estimation of the accelerating fields occurring as the result of the inverse Cherenkov effect and the inverse effect of polarization losses when a charged particle bunch moving in a longitudinal magnetic field \vec{H}_0 is entrained by an electron beam. The space charge of the beam is assumed to be compensated by positive ions. The field excited by the particles is described by Maxwell's equations and by the equations of motion of the plasma particles. The voluminous integral in the expression for the energy losses $\frac{d\epsilon}{dx}$ of the particle is considerably simplified when the

magnetic field is either very weak ($v \ll 1$) or very strong ($v \gg 1$):

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$$\frac{d\epsilon}{dx} = -\frac{q^2\Omega^2}{2V^2} \left\{ \ln \left(1 + \frac{V^2}{a^2\Omega^2} \right) - \frac{\omega_H^2(1-\beta^2)}{6\Omega^2} (9-4\beta^2) \right\}. \quad (4)$$

and

$$\frac{d\epsilon}{dx} = -\frac{q^2\Omega^2}{2V^2} \left\{ (1-\beta^2) \ln \left[1 + \frac{V^2}{(1-\beta^2)\omega_H^2 a^2} \right] - 1 \right\} \quad (5),$$

respectively. q is the charge of the moving particle. The first term of these two formulas corresponds to the excitation of frequencies having the

order of magnitude $\Omega = \sqrt{4\pi n_0 e^2/m}$, whereas the second term corresponds to the excitation of frequencies whose order of magnitude is $\omega_H (\omega = \vec{k}\vec{V})$.

$v = eH_0/mc\Omega$, $\beta = \frac{V}{c}$. For small values of V , (5) is not valid since the condition $V \gg a\Omega$ does not continue to apply. The quantity $a = 1/k_{\max}$ is determined by the minimum parameter for remote collisions between the particles and the electrons of the beam. The upper limit for the energy losses, obtained by inserting the minimum value of the particle velocity $V \sim a\Omega$ in (5),

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is not much affected by the magnetic field. A charged particle moving parallel to an electron beam (V_0) loses the energy;

$$\frac{d\epsilon}{dx} = -\frac{q^2\Omega^2}{2V(n)^2} \frac{V(V-V_0)}{[V(V-V_0)]} \ln\left(1 + \frac{V(n)^2}{u^2\Omega^2}\right). \quad (10).$$

This particle loses energy if $V > V_0$ and gains energy if $V < V_0$. In an electron beam a bunch practically behaves like a single particle if $\exp[ik(\vec{r}_j - \vec{r}_1)] \sim 1$. In this case, $k_{\parallel \text{eff}} b_{\parallel}^{(r)} \ll 1$ and $k_{\perp \text{max}} b_{\perp}^{(r)} \ll 1$ (11). $b_{\parallel}^{(r)}$ and $b_{\perp}^{(r)}$ are the longitudinal and parallel dimensions of the bunch in a system where the bunch is at rest. The projection of the field on the direction in which the bunch moves remains below the limit $E_{\text{max}} \sim \frac{qN}{b^2}$, where N is the number of particles in the bunch, b is the greatest length of the bunch. This paper was composed in 1952.

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44890

S/861/62/000/000/021/022
B125/B108

AUTHORS: Faynberg, Ya. B., Kurilko, V. I.

TITLE: On the theory of acceleration by means of the pressure of light

SOURCE: Teoriya i raschet lineynykh uskoriteley, sbornik statey. Fiz.-
tekhn. inst. AN USSR. Ed. by T. V. Kukoleva. Moscow,
Gosatomizdat, 1962, 326 - 332

TEXT: The radiation of an oscillator produces a pressure that is
 $\lambda_0^2/(e^2/mc^2)^2$ times as high as that produced by the radiation of a free
charge. This is investigated in nonlinear approximation. The motion of a
charge in the constant magnetic field $H_z = H_0$ is studied under the action
of a plane polarized monochromatic wave $E_x = H_y = E_0 \cos(\omega t - kz)$ propagating
along the constant magnetic field. Considering that $\epsilon \ll 1$ (true in most
cases that are important in practice) and $\gamma = \frac{2}{3} \frac{1^2}{mc^2 \lambda_0} \ll 1$ (true in classical
consideration), and allowing for the radiation, the nonlinear equations of
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On the theory of acceleration...

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motion for the particle lead to a slightly nonlinear equation for $u_k = dx_k/ds$,
and in the case of steady motion to

$$\left. \begin{aligned} \theta &= \arctg \frac{1-b}{\gamma(1+a^2)} \\ \frac{1}{4} \frac{e^2}{\Omega^2} b^2 &= a^2(1-b)^2 + \gamma^2(1+a^2)^2 \end{aligned} \right\} \quad (6)$$

for amplitude and phase, using the substitution $u_2 = -a \sin(\Omega v + \theta)$. For
 $\theta \rightarrow 0$ a formula is derived from (6) for v_1/c leading to

$$\begin{aligned} \frac{d}{dt}(p)_z &= \frac{e}{c} (v, H)_z = \frac{1}{2} e E_0 \beta_1 \cos \theta = \\ &= \begin{cases} \frac{e}{4\gamma} (1 - \beta_z) e E_0, & \frac{e}{2\gamma} (1 - \beta_z)^{1/2} \ll 1, \\ \frac{1}{2} (1 - \beta_z)^{1/2} e E_0 - \frac{\gamma}{8} \dots, & \frac{e}{2\gamma} (1 - \beta_z)^{1/2} \gg 1. \end{cases} \quad (9) \end{aligned}$$

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for the radiation pressure. According to these formulas the force of the radiation pressure exerted on the oscillator as averaged over one period cannot exceed $eE_0/2$, and tends toward the value following from the linear theory if $\epsilon(1-\beta_z)^{1/2} \ll 2\chi$. These estimates apply if the accuracy of the field is sufficient for a precise resonance. Avoiding the complex equations of interaction, the most important properties of a bunch can be determined from investigating a particle having the mass $M=Nm$ and the charge $z=Ne$. A bunch and a single oscillator furnish identical results if $N\chi \ll 1$. With a bunch of that type resonance is achieved even if the field is maintained less accurately. The exact equations of motion considering the radiation pressure, can, by averaging, be reduced to linear Eqs.

$$\left. \begin{aligned} \frac{da}{d\tau} &= (1 - \beta_z^2 - a^2)^{1/2} \left\{ \frac{\epsilon}{2} (1 - \beta_z - a^2) \cos \theta - \gamma a \right\}; \\ \frac{d\beta_z}{d\tau} &= \frac{\epsilon a}{2} (1 - \beta_z^2 - a^2)^{1/2} (1 - \beta_z) \cos \theta; \\ \frac{d\theta}{d\tau} &= (1 - \beta_z^2 - a^2)^{1/2} \left\{ 1 - \frac{\Omega(1 - \beta_z)}{(1 - \beta_z^2 - a^2)^{1/2}} \right. \\ &\quad \left. - \frac{\epsilon}{2a} (1 - \beta_z) \sin \theta \right\}. \end{aligned} \right\} \quad (10)$$

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that are not explicitly dependent on time. These considerations apply also when $\epsilon \gg N\gamma$. This paper was presented to the Uchenyyi sovet Fiziko-tekhnicheskogo instituta AN USSR (Scientific Council of the Physicotechnical Institute AS UkrSSR) in November 1956.

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AUTHOR: Faynberg, Ya. B.

TITLE: Some problems of particle acceleration in a plasma

SOURCE: Teoriya i raschet lineynykh uskoriteley, sbornik statey. Fiz.-
tekhn. inst. AN USSR. Ed. by T. V. Kukoleva. Moscow,
Gosatomizdat, 1962, 333 - 346

TEXT: The present paper bases mainly on a previous work of the author in
Atomnaya energiya, 6, no. 4, 1959. Further development of accelerating
methods as worked out by V. I. Veksler (Proc. Symp. CERN, 1, 80 (1956)) and
G. I. Budker (Proc. Symp. CERN, 1, 68 (1956)) for high energies and high
currents is very promising. The h-f power required in linear accelerators
can be reduced considerably by concentrating the electromagnetic energy to
the range in which the accelerated particle is moving momentarily.
Accelerating fields of more than 200 - 300 kv/cm can be achieved only if
the metallic surfaces in the accelerating system are removed either com-
pletely or at least to a great extent. To achieve a strong current, the
radial and the phase stability must be high. The Doppler effect occurring
when electromagnetic waves are reflected from a moving plasma, and the
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interaction of a charged particle beam can be used to convert plasma energy into electromagnetic radiation. Plasma wave guides and non-compensated beams allow the electromagnetic energy to be concentrated in systems that have a small cross section. A confined plasma and uncompensated beams act as wave guides with insignificant losses already at plasma densities as low as $10^9 - 10^{13} \text{ cm}^{-3}$. The plasma wave guides are transparent to the particles to be accelerated and permit simultaneously of both radial and phase stability without necessitating the use of additional focusing means. The condition of radial stability for an arbitrary shape of field is

$$-\frac{e_{zz}}{e_{xx}} \frac{1}{LV} \left(1 - \frac{v^2}{c^2} e_{xx}\right) \int_0^L \frac{\partial E_z}{\partial t} dz + \omega_L^2 + \frac{c}{L} \frac{e_{xy}}{e_{xx}} \int_0^L \frac{\partial H_z}{\partial t} dz > 0,$$

The E and H-waves that are present simultaneously in gyrotropic plasma wave guides offer a means for a linear-cyclic acceleration. The amplitude of the radial oscillations can be decreased considerably when the frequency is varied by a proper choice of the dielectric constants ϵ_1 , ϵ_2 and ϵ_3 of the (anisotropic) plasma. Brillouin electron clouds have an additional focusing

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effect and behave like wave guides for E waves propagating in the direction of the magnetic field. Hence, Gabor electron lenses can be used for accelerating charged particles. The condition of radial focusing is then given by

$$2\pi\omega_p^2 \frac{M}{m_0} (1 - \beta_z^2)^{1/2} + \frac{\pi E_0}{\beta_z \lambda M} \left[-1 + \frac{v_z^2}{c^2} \left(1 - \frac{\omega_0^2}{\omega^2} \right) \right] > 0.$$

The coherent energy losses can be eliminated by increasing the plasma density and the wavelength of the accelerating field. In nonlinear approximation the phase velocity of the wave depends on the frequency and on the wave amplitude. Hence, the phase velocity of the wave can be varied (up to rather high values) by changing the amplitude of the accelerating field.

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S/ 751/62/000/000/003/035

AUTHOR: Zagorodnov, O. G., Faynberg, Ya. B., Yegorov, A. M., Kivshik, A. F.

TITLE: Reflection of electromagnetic waves from a moving plasma. Investigation of waveguide properties of a plasma

PERIODICAL: Fizika plazmy i problemy upravlyayemogo termoyadernogo sinteza; doklady i konferentsii po fizike plazmy i probleme upravlyayemykh termoyadernykh reaktsiy. Fiz.-tech. inst. AN Ukr. SSR. Kiev, Izd-vo AN Ukr. SSR, 1962, 9-20.

TEXT: The first part of the article describes experiments on the reflection of slow electromagnetic waves from a moving plasma, aimed at ascertaining whether the frequency multiplication and increase in the reflected-wave amplitude attainable in the case of slow waves is sufficient to lead to the development of new methods of amplification of microwaves and acceleration in a plasma, and also to stabilize a plasma. Since the Doppler shift in the frequency and the change in the amplitude of an electromagnetic wave reflected from a moving mirror can be made appreciable only by increasing greatly the velocity of the reflecting surface or

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by changing the phase velocity of the wave in the space where the interaction takes place, and since it is not practical to obtain high physical mirror velocities (even when an electron beam or a plasma is used as a reflecting surface), the experiment was carried out with an electromagnetic wave of a phase velocity slowed down to that of the reflecting plasma. The slow-wave structure consisted of a helical waveguide comprising a porcelain tube 40 mm in diameter, with a helix made of copper wire 0.4 mm in diameter wound at a pitch of 0.8 mm. The experimentally measured phase velocity in the helix was $v_{ph}/c = 1/200$. A plasma piston was produced by discharging a 750 microfarad capacitor bank charged to 4.5 kV. At 24.75 Mcs, the frequency of the reflected wave was found to be increased by 11 per cent relative to the incident wave, and when the phase velocity was decreased to $1/375$ of the velocity of light, the frequency increased by 20 per cent. The velocity of the plasma piston was calculated to be $v = 8.45 \times 10^6$ cm/sec. This effect can be used for amplification and generation of microwaves, acceleration of particles, and various measurements in plasma and also to increase the stability of a plasma.

The second part of the investigation was devoted to waveguide properties of plasma. A plasma waveguide was produced by a high frequency discharge in a quartz tube 1500 mm long,

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in which a vacuum of 7×10^{-3} mm Hg was maintained. The plasma density in the waveguide could be varied up to 10^{11} cm $^{-3}$. A slow electromagnetic wave of low power (on the order of 1 watt) at frequencies from 150 to 2000 Mcs was excited in the plasma waveguide, and the resultant phase velocity of the standing wave was measured as a function of the frequency for different plasma densities and for several values of longitudinal magnetic field. A study of the dependence of the waveguide field intensity on the high-frequency power applied to the plasma (in the range from 100 to 1.5 kW) has shown this dependence to be non-monotonic, probably owing to resonance in the plasma column. Other quantities measured were the radial dependence of the longitudinal component, the nonlinear distortion of low-power signals passing through the plasma waveguide and the microwave losses in the plasma waveguide. The acceleration in the plasma was investigated by means of a small model of a helical-plasma accelerator. An analysis of the energy spectrum of the beam, made by electrostatic deflection, shows that the spectrum is quite broad and that a considerable fraction of the electrons had the expected energy near 5.5 keV. This shows that the field is capable of penetrating and reaching the axis of the plasma and that the electrons become accelerated.

K. D. Sinel'nikov is credited with suggesting one possible reason for signal distortion in the

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